Research article

Soil Health Assessment of Soil under *Miscanthus* × *giganteus* Cultivation

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Abstract Soil health is the capacity of soil to function as a living ecosystem that sustains plants, animals, and humans. Healthy soils support the optimal crop yields and also plays a crucial role in protecting water quality and other aspects of environmental stewardship. Meanwhile, the agricultural damage by the earthquake causes serious crop productivity degradation in Japan. Thus, there is a need for research on crop productivity, especially land under the earthquake disaster. In addition, the global demand for renewable energy resources such as *Miscanthus* spp., mainly the triploid interspecific hybrid *Miscanthus* × *giganteus* (M × g), has increased substantially. Because it has the potential to have a high yield, sequester the carbon into the soils, and improve the soil health. Therefore, the objective of this study was to demonstrate soil health index assessment at *Miscanthus* spp. fields. We investigated (1) to quantify the impact on land use changes including Miscanthus, pasture, and arable land on soil health index. T soil under *M* × *g* increases the over-all SHI value to compare another land use. Therefore, it can be concluded that *M* × *g* is the better land use management option in the cool climate regions such as Northern Japan.

Keywords soil health, soil management assessment framework, *Miscanthus* × *giganteus*

INTRODUCTION

What is a good soil or a bad soil? That is the ultimate question for soil scientists. The soil scientists have been trying to answer that question as well as to find out the way to ensure the soil health. Soil health is defined as the capacity of soil to function to sustain plant and animal productivities, to maintain or improve water and air qualities and to support human health and habitation (Karlen et al., 1997). Soil health index (SHI) assessment involves an evaluation of soil physical, chemical, and biological attributes to know how well the resource is functioning. Therefore, SHI assessment seeks to characterize the overall agro-ecological functions of soil by selecting soil physical, chemical, and biological properties as indicators, measuring them, and calculating a score or index for both the individual properties and overall soil health (Nakajima et al., 2015). Miscanthus spp., as source of biomass energy crop mainly the triploid interspecific hybrid Miscanthus × giganteus (*M* × *g*), has increased drastically. The *M* × *g* has the potential to mitigate greenhouse gas emissions by replacing fossil fuels, sequestering carbon into the soils, and improve soil health (Clifton-brown et al., 2004, Guzman and Lal, 2014). In addition, the *M* × *g* requires low annual energy net and financial inputs, including tillage, planting, and practical management such as fertilizer, herbicide, and pesticide application. Yet, the effects of SHI on soil under *M* × *g* cultivation vary by climate, soil type, management practices, and former land use history. Thus, there is a need for site-specific research on *M* × *g* of SHI.

OBJECTIVES

The objective of this study was to demonstrate SHI assessment at *M × g* fields. We specifically investigated to quantify the impact on land use changes including *M × g*, *M. sinensis*, pasture, and arable land on SHI. The hypothesis tested in this study was that soil under *M × g* increases the over-all SHI value to compare another land use.

METHODOLOGY

Study Site and Soil Sampling

The study site was established in 2009 at the Experiment Farm of the Field Science Center for Northern Biosphere, Hokkaido University, Sapporo, Japan (43°04′22″N, 141°20′16″E). According to the Japan Meteorological Agency, the annual average temperature and annual precipitation were 9.48 °C and 1209 mm, respectively from 2009 to 2015. The soil at the study site is classified as Humic Andosols. The undisturbed soil core samples were collected with 100 cm^3 steel soil core sampler (height = 5.0 cm, diameter = 4.8 cm) using a cylindrical hammer-driven core sampler for soil depths of 0-5 cm, with three replicates. In addition, disturbed soil samples were obtained for soil layers at depths of 0-5 cm, with three replicates per plot, using a hydraulic soil sampling device (FV-477, Fujiwara Scientific Company Co., Ltd., Okayama, Japan). The soil samples were homogenized by replicate and sieved through 2 mm sieve and air-dried before the analysis.

Photo. 1 *Miscanthus* × *giganteus* and soil sampling at arable land

Soil Health Assessment

The SHI assessment was conducted by: (1) identifying a minimum data set of indicators, (2) selecting indicator interpretation criteria, and (3) integrating all indicator scores into an overall SHI value (Andrews, et al., 2004, Nakajima, et al., 2015).

The SHI was basically computed by using the Soil Management Assessment Framework (SMAF) (Andrews et al., 2004, Karlen et al., 2001). The details for each step of the SHI assessment is summarized as follows.

1. First, the minimum data set of soil physical, chemical, and biological indicators was selected for evaluating for the management goal. The indicators were selected based on literature review (Andrews et al., 2004, Nakajima et al., 2015).
2. For the second step, the minimum data set indicators were converted into unit less scores ranging from 1 to 5 using the criteria presented in Table. 1. In general, there are three shapes of scoring functions (Karlen and Stott, 1994, Wymore, 1993). If soil quality is improving as level of an indicator increases, a "the more is better" curve is used. Conversely, a "less is better" curve is suitable if soil quality is decreasing as the indicator value rises. Finally, a "optimum" curve is used for those indicators that have an increasingly positive association with soil quality up to an optimal level, but beyond which, soil quality decreases.
3. Finally, after selecting the appropriate curve type and scoring individual indicators, the unit less values can be incorporated in a single. Overall SHI value with appropriate weighting of individual indicators if needed.

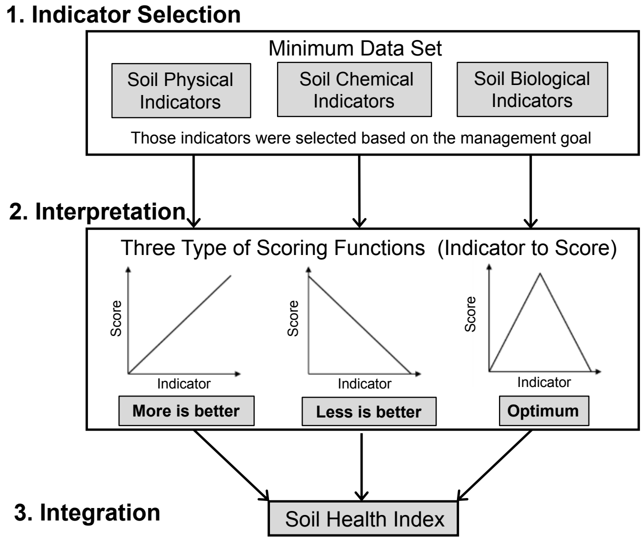

Fig. 1 Conceptual framework for soil health index scoring function analysis adapted from Andrews et al., 2004

Table 1 Scoring function chart for interpretations soil health index with source references

Indicator	Unit	5	4	3	2	1	Reference
BD	Mg m^{-3}	<1.2	1.2-1.3	1.3-1.4	1.4-1.5	>1.5	Lal (1994)
Texture	-	Loam	Silt loam, Silt, Silty clay loam	Clay loam, Sandy loam	Silty clay, Loamy sand	Clay Sand	Lal (1994)
pH	-	6.0-7.0	5.8-6.0, 7.0-7.4	5.4-5.8, 7.4-7.8	5.0-5.4, 7.8-8.2	<5.2, >8.2	Andrews et al. (2004)
EC	μS m^{-1}	<300	300-500	500-700	700-1000	>1000	Lal (1994)
SOC	g kg^{-1}	>50	30-50	10-30	5-10	<5	Gregorich et al. (1994) Lal (1994)
MWD	mm	>2.5	2.0-2.5	1.0-2.0	0.5-1.0	<0.5	Lal (1994)

Statistical Analysis

Analysis of variance (ANOVA) was conducted, and comparisons between the *M* × *g*, *M. sinensis*, pasture, and arable land were performed R Studio (Studio, 2012). Statistical significance was determined when $P \leq 0.05$, unless otherwise stated.

RESULTS AND DISCUSSION

Implementation of SHI Analysis

Among all sites, the SHI ranged from 0.59 to 0.72, and the SHI under *M* × *g* (0.72) was slightly higher than that under arable land (0.59), but with no statistical differences. The SHI were significantly affected among the sites. However, *M* × *g* cultivation could improve the SHI from results SHI assessment. It implies that under the *M* × *g* in Northern Japan influence soil health due to their nutrient cycling between the rhizome and aboveground biomass, and recycling of nutrients from leaf litter and the soil. In addition, this has several possible explanations after the establishment of *M* × *g*, there was no major loss in SOC due to the minimal soil disturbance caused by the introduction of the perennial rhizomatous grass (Zimmermann et al., 2012).

Table 2 Correlation coefficients for each soil physical and chemical properties

	BD	SOC	pH	EC	Texture	MWD
BD	1.000					
SOC	0.202	1.000				
pH	0.089	0.466	1.000			
EC	0.289	0.177	0.336	1.000		
Texture	0.013	0.286	0.772*	0.024	1.000	
MWD	0.144	0.808*	0.650*	0.222	0.396	1.000

** Significant at the 0.05 level.*
BD: bulk density (Mg m^{-3})
SOC: soil organic carbon (g kg^{-1})
EC: electric conductivity (mS m^{-1})
MWD: mean weight diameter from soil aggregation analysis (mm)

The SOC, pH, MWD, Texture were the important key indicators for SHI assessment in this study sites. For soil chemical function, the pH had the highest correlation coefficient. Other important measured attributes were SOC and MWD. However, BD and EC were less responsive to the management practices in comparison to other indicators.

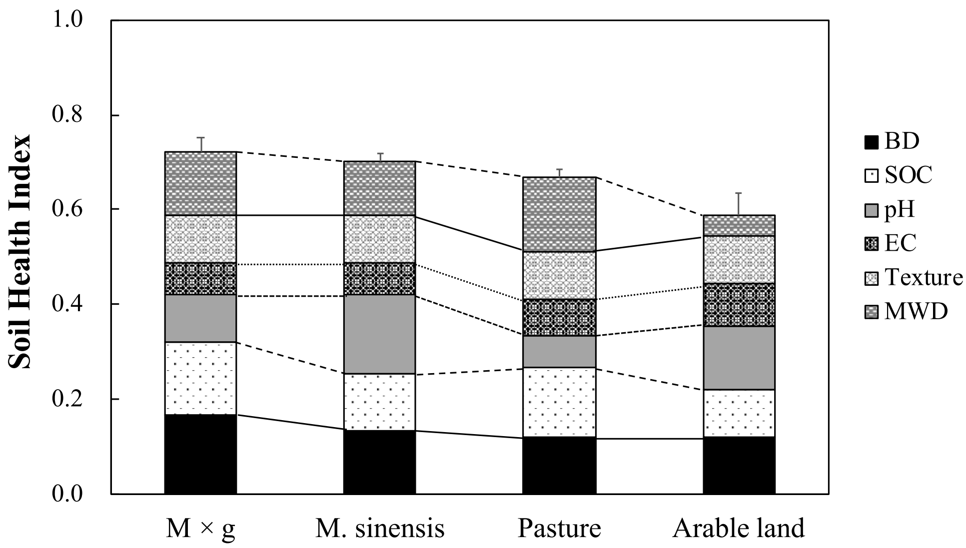

Fig. 2 The soil health index (SHI) at *M × g*, *M. sinensis*, pasture, and arable land Error bars indicate standard error

CONCLUSION

This study demonstrates SHI assessment using scoring function analysis for different sites. The hypothesis tested in this study was that soil under *M × g* increases the over-all SHI value to compare another land use was supported by the results. Therefore, it can be concluded that *M × g* is the better land use management option in the cool climate regions such as Northern Japan. Quantitative assessments of soil health may be useful for optimizing land use plans. However, valid, reliable, sensitive, repeatable, and accessible indicators must be identified and framework for overall evaluation of soil quality must be developed (Nakajima et al., 2015).

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